Developing a Mechanistic Water Balance Model, to Predict Green Roof Performance and Efficiency

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Our Vision

- *Quantify* green roof benefits within the Mid-Atlantic region, and beyond
- *Provide tools* to measure the efficiency of green roofs
- Increase our knowledge of green roof *system performance*, to inform the industry and design process

Prime Performance Objective

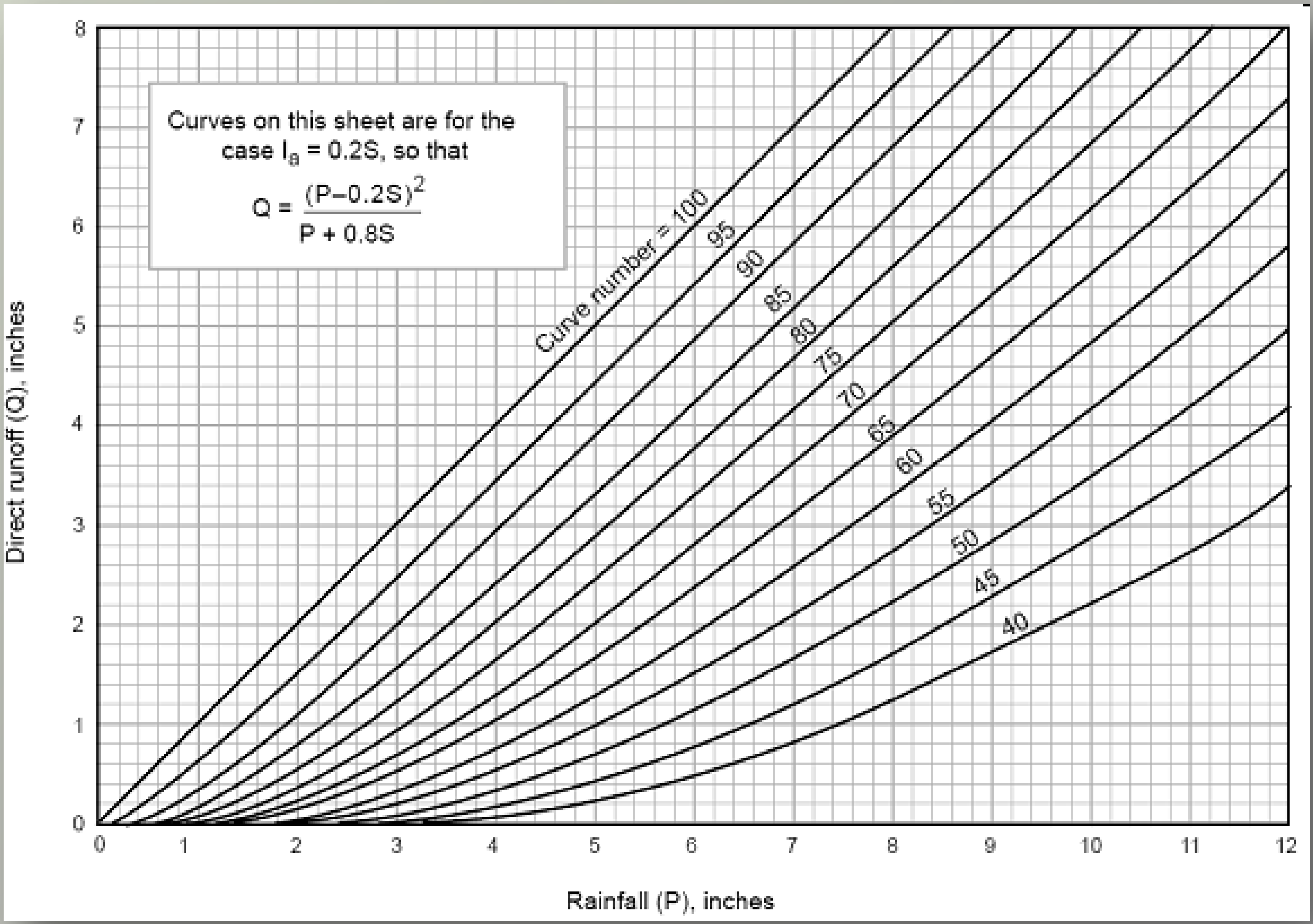
- Quantifying Stormwater runoff
- Quantifying thermal benefits

Stormwater Retention / Runoff

Quantifying Runoff

- Traditional (Curve Number) Approach
- **System-based Approach**

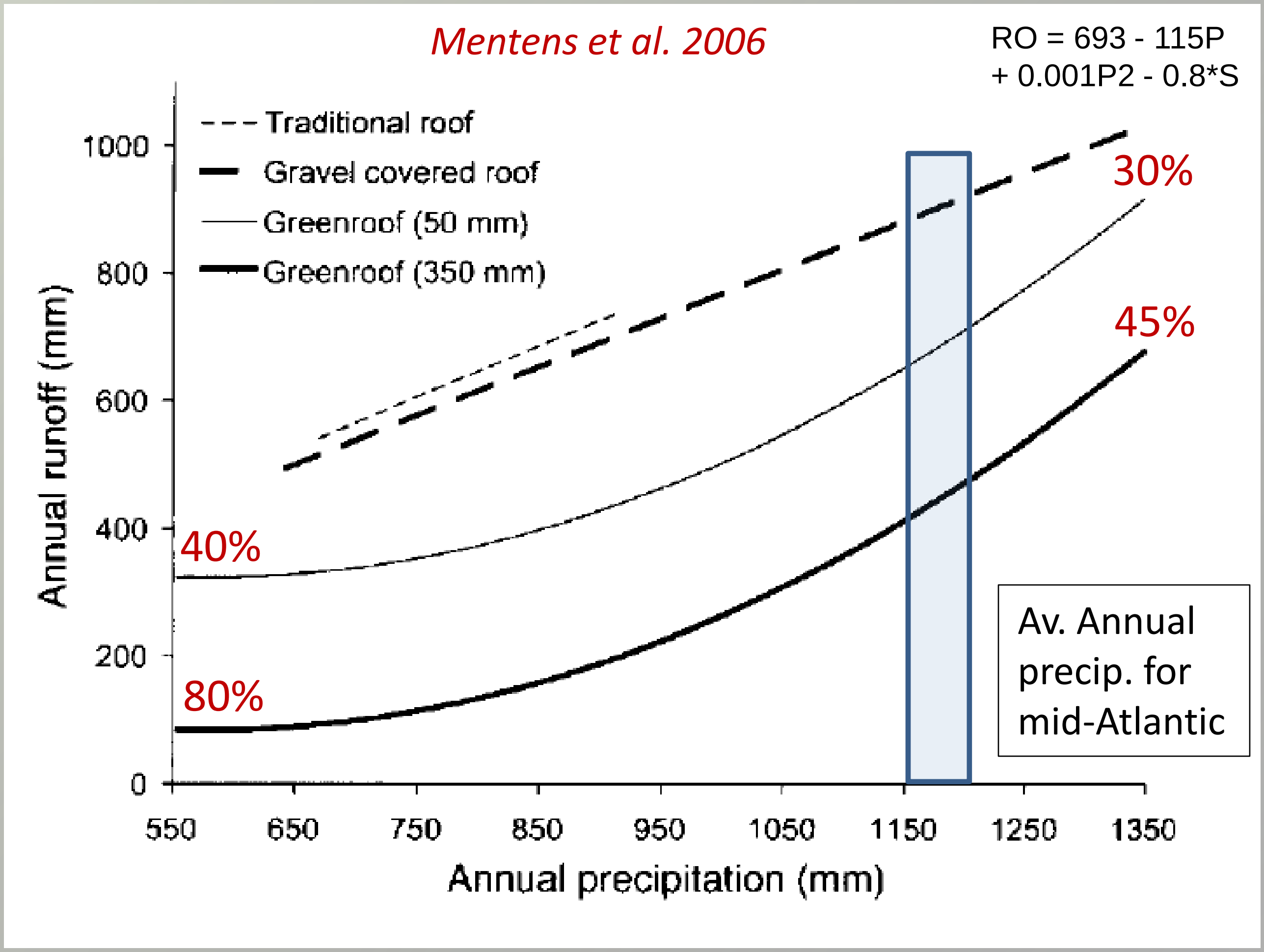
Stormwater Retention / Runoff



Q: How much stormwater is retained by a green roof?

Retention by green roofs varies according to storm size

… and many other system parameters



Stormwater Retention / Runoff

Quantifying Runoff

- Expensive (especially in retrofit situations)
- Total runoff does not inform the design process

(i.e. difficult to understand which design parameters contribute most to efficiency)

$\Rightarrow$ Hence the advantage of modeling

Quantifying Runoff

Simple Water Balance Approach

i.e., A – B = C, where:

(A)		(B)		(C)
Rainfall (INPUT)	–	System removal ($\delta E_T / \delta t$)	=	Runoff

So -- if we know A and B at any given time, we can predict C (= Ĉ)

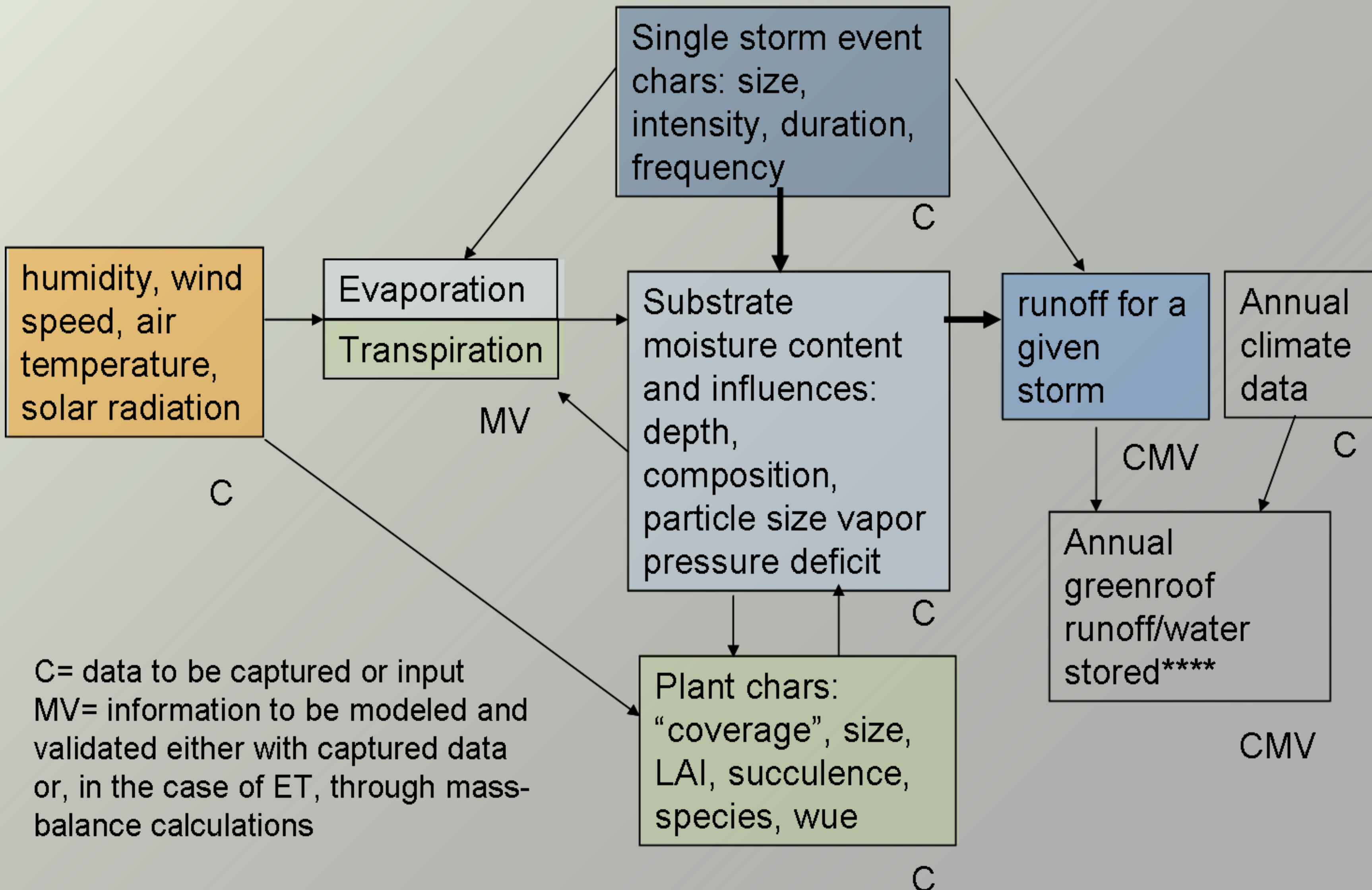
Predicting Runoff

But, we recognize that the system removal (δE_T) changes over time (δt), due to:

- Canopy coverage, leaf area
- Seasonal (species-specific) differences in transpiration rate
- Substrate physical properties
- Root density

We need to include these biological and physical parameters in the model, to ensure that predicted runoff, $\hat{C} = A - B$

Modeling the Green Roof Water Cycle



C= data to be captured or input
MV= information to be modeled and validated either with captured data or, in the case of ET, through mass-balance calculations

Translating Theory into Practice

Predicting Runoff (Efficiency)

- Model - Data Integration
- Tool Development

Modeling the Green Roof Water Cycle

We are using a sensor network / modeling approach, which integrates the model variables, over time:

Every 5 minutes, we measure:

1. Rainfall [Input]

2 a. Temperature and Relative Humidity (=VPD)

2 b. Radiation (total light)

2 c. Wind speed

to predict plant Evapotranspiration (E_T) , using a modified Penman-Monteith Equation

Modeling the Green Roof Water Cycle

Every 5 minutes, we measure:

3. Substrate moisture content (VWC)

Which integrates:

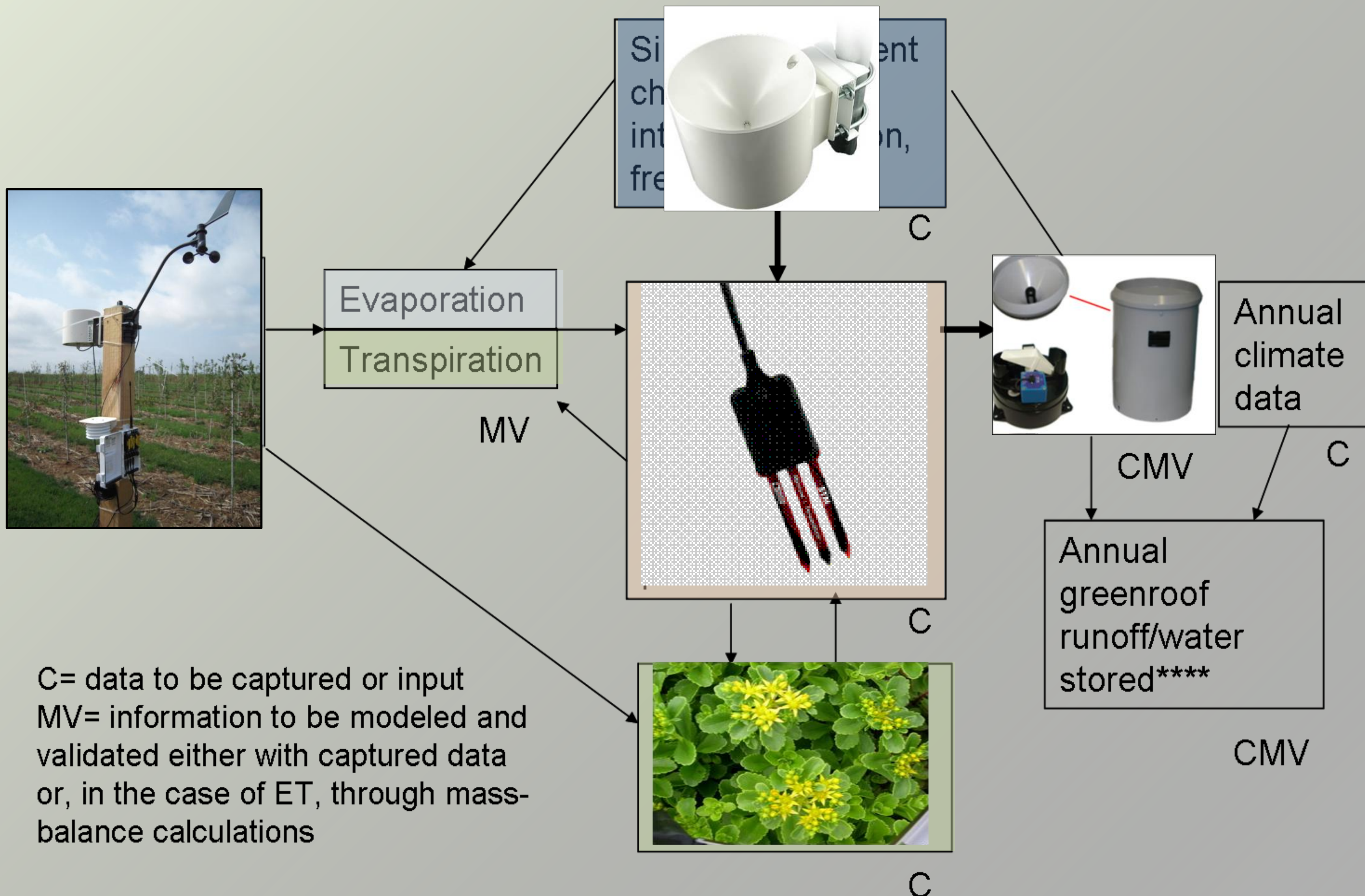
a. Amount of *available* water at any one time
b. Plant water use
c. Changes in VWC over time
   (due to changes in physical properties, increased root density, organic matter etc)

Modeling the Green Roof Water Cycle

Every 5 minutes, we measure:

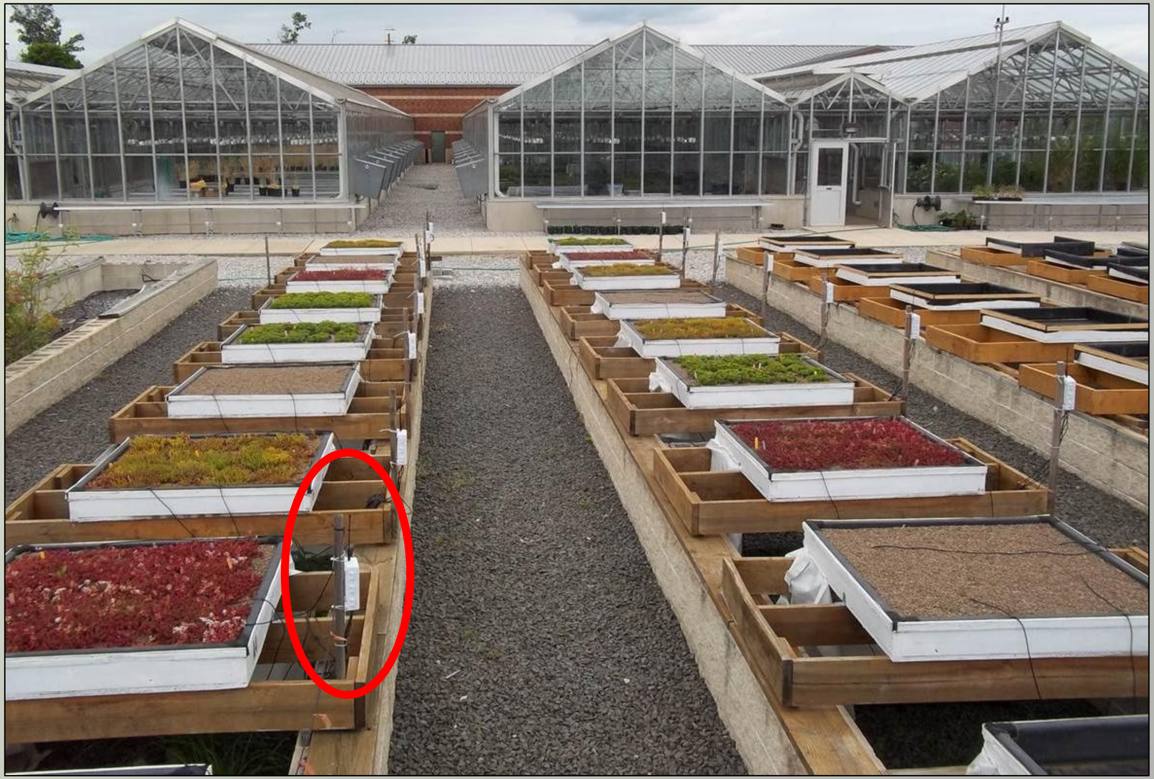
4. Actual Runoff (with rain gauges)

which verifies the predicted model runoff


C
Evaporation
Transpiration
MV
Annual climate data
C
CMV
C
Annual greenroof runoff/water stored****
CMV
C
C= data to be captured or input
MV= information to be modeled and validated either with captured data or, in the case of ET, through mass-balance calculations

Green Roof Experimental Site (2010)

Green Roof Experimental Site (2011)



Three Sedum Species:

- *S. album*
- *S. kamtschaticum*
- *S. sexangulare*

Control:

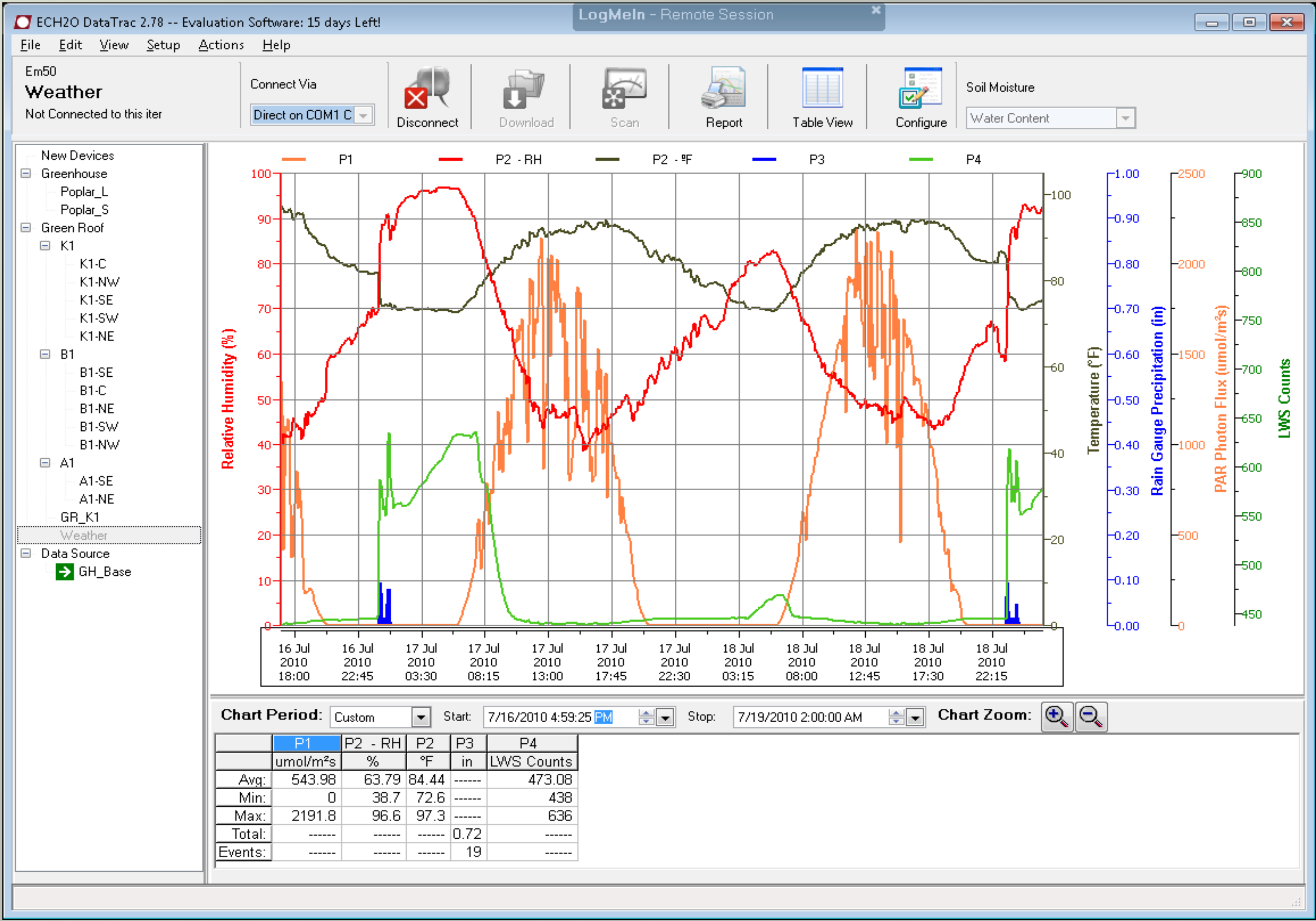
- *No plants*

  (M2 substrate)

Randomized Complete Block Design:

- (4 replicates)

Wireless Sensor Network Data:



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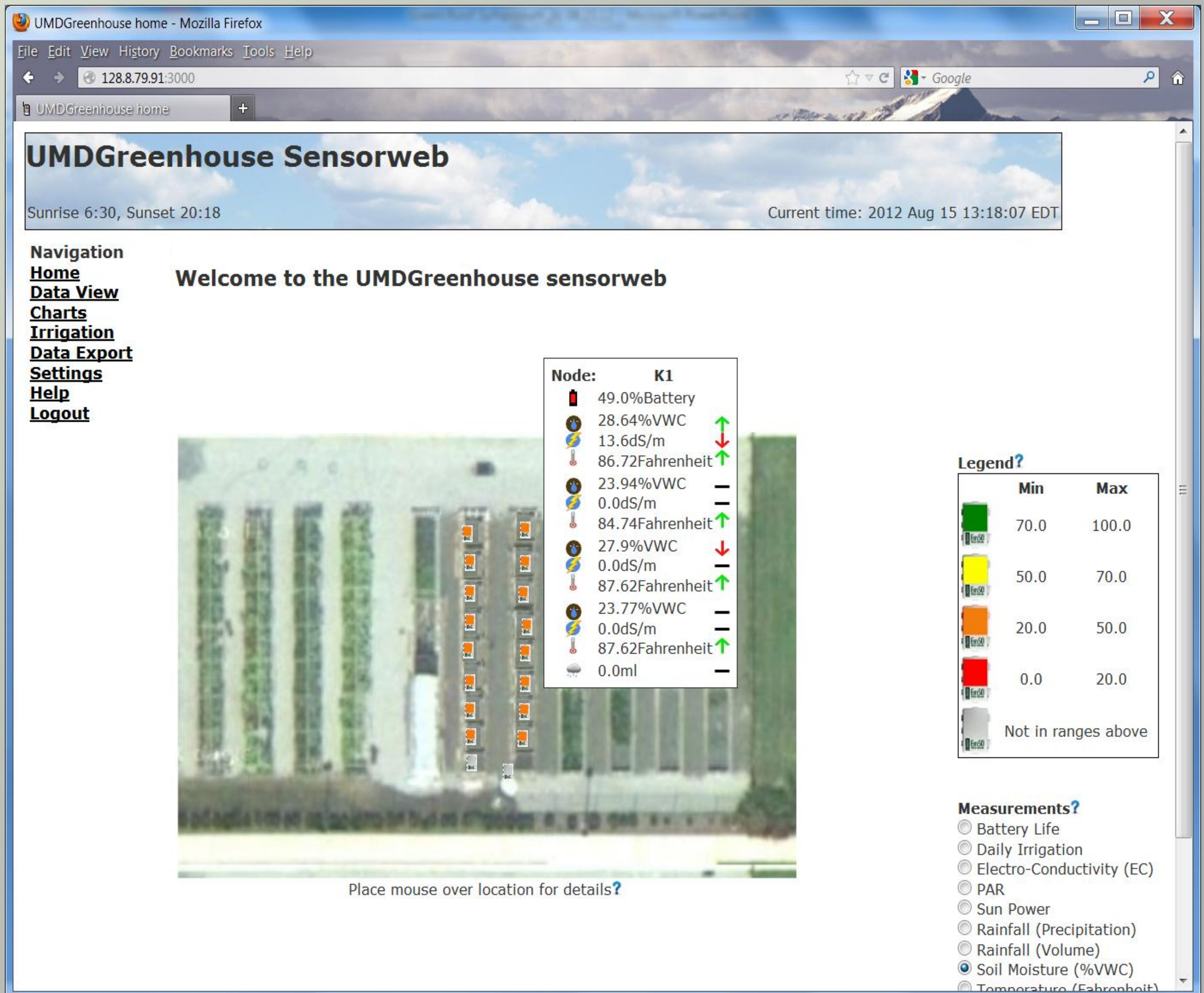
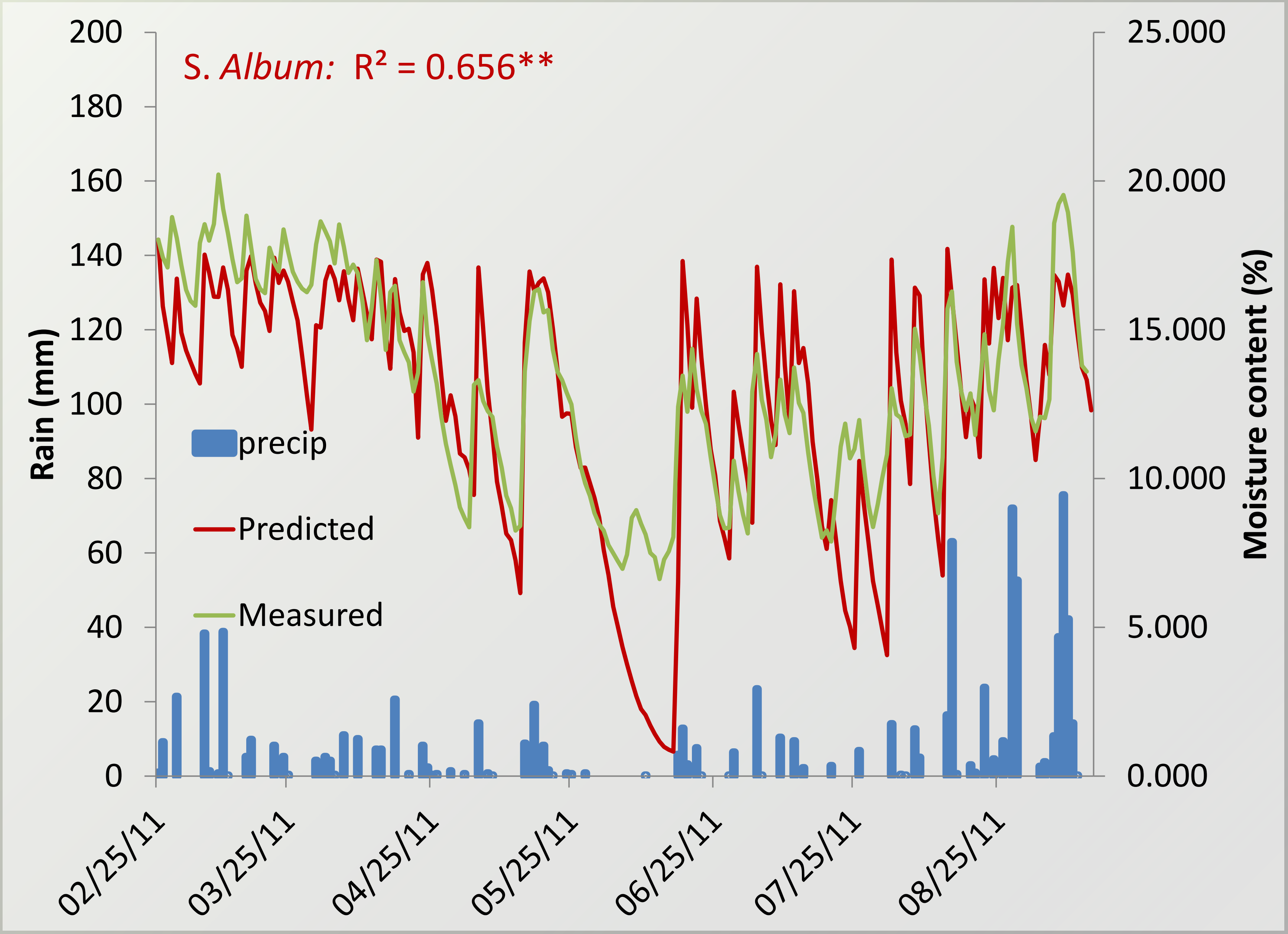
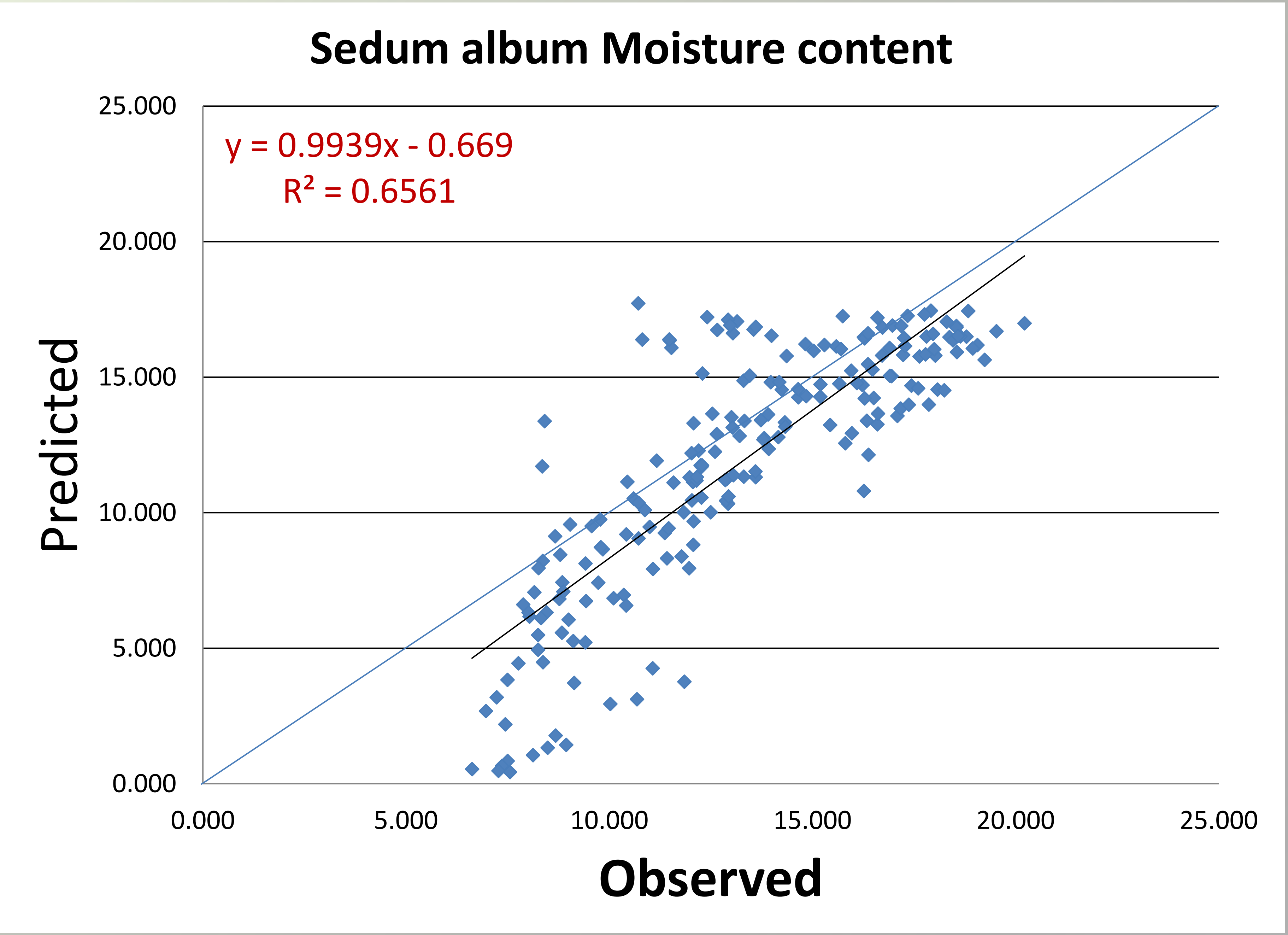
Data Integration into Sensorweb Tool



Model Verification (2011)





Sedum album Moisture content
y = 0.9939x - 0.669
R² = 0.6561
Predicted
Observed
25.000
20.000
15.000
10.000
5.000
0.000
0.000
5.000
10.000
15.000
20.000
25.000

Further Development / Issues

- Model Refinement:
  - Slope, perhaps aspect component
  - Changes in substrate components over time -- both biological and physical
  - Lag-to peak issues with measuring actual retention (various scaling issues)

- Data Management:
  - Web-based interface, customizable for individual green roofs is our immediate goal (next 12-18 months)
  - Desktop application (individual managers)
  - Cluster-capability (multiple green roof analysis tool) on the cloud

Benefits

- Cost -- relatively low-cost, low maintenance system
- Retrofit – large cost benefit if this approach works, since retrofitting existing green roofs with rain gauges or flumes is costly (and painful) to get good data
- Model Approach – allows for what-if scenario building and sensitivity analyses

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